DOCUMENT-IDENTIFIER: US 5797845 A
TITLE: Ultrasound apparatus for three dimensional image reconstruction

---------- KWIC ---------

DEPR:
FIG. 12 describes the schematic of the generation of the acoustic wave packages and schematic of the signal processing of the echo signals. As it is seen from the figure, transmit and receive array systems are separated. The pulse driver 47 has timing circuitry and the necessary set of generators. They perform the functions of the transmit system 22 in the phased mode with dynamic focusing and scanning of the beam and are connected with individual elements 28 of the transmit array 22 by cables 48. Individual elements 28 of the receive array 23 register the echo signals and are connected by cables 45 with reception parts 49 and 50 of the apparatus which provides amplification of the echo signals, conversion of them in the digital code and recording of amplitude information from every receive array individual element in the memory for every focal distance. Adjustment of the dynamic receive apertures is produced by shifting the individual element information by the number of digits corresponding to the delay for every individual element. After this, individual element information is summed and presented as part of the acoustic line for every selected aperture. Thus, the sector of the 2D image is

US005797845A

United States Patent [19]

Barabash et al.

[11] Patent Number: 5,797,845

[45] Date of Patent: Aug. 25, 1998

[54] **ULTRASOUND APPARATUS FOR THREE DIMENSIONAL IMAGE RECONSTRUCTION**

[76] Inventors: **Leonid S. Barabash**, 13021 S. 48th St., Apt. 2097; **Aaron E. LaBarge**, 3914 E. Nambe St., both of Phoenix, Ariz. 85044; **Angel T. M. Wang**, 4700 Sandyland Rd. Apt. 37, Carpenteria, Calif. 93013

[21] Appl. No.: **742,403**

[22] Filed: **Nov. 4, 1996**

[51] **Int. Cl.**[6] **A61B 8/00**

[52] **U.S. Cl.** **600/443**; 600/459; 128/916

[58] **Field of Search** 128/916, 660.07, 128/660.01, 661.01; 600/443, 447, 459

[56] **References Cited**

U.S. PATENT DOCUMENTS

4,766,554	8/1988	Sarr et al. .	
4,949,310	8/1990	Smith et al.	128/660.01
5,103,129	4/1992	Slayton et al. .	
5,159,931	11/1992	Pini .	

OTHER PUBLICATIONS

Chris M.W.Daft et al., "Beam Profiles and Images from Two-Dimensional Arrays", Ultrasonics Symposium, 1990, p. 775.

Marshall T. Robinson and Olaf T. von Ramm, "Real-Time Angular Scatter Imaging System for Improved Tissue Contrast in Diagnostic Ultrasound Images", IEEE Trans. on Ultrasonics, Ferroeletrics and Frequency Control, vol. 41, No. 1, Jan. 1994.

S.W.Smith et al., "Two-Dimensional Arrays for Medical Ultrasound", Ultrasonics Symposium, 1991, p. 625.

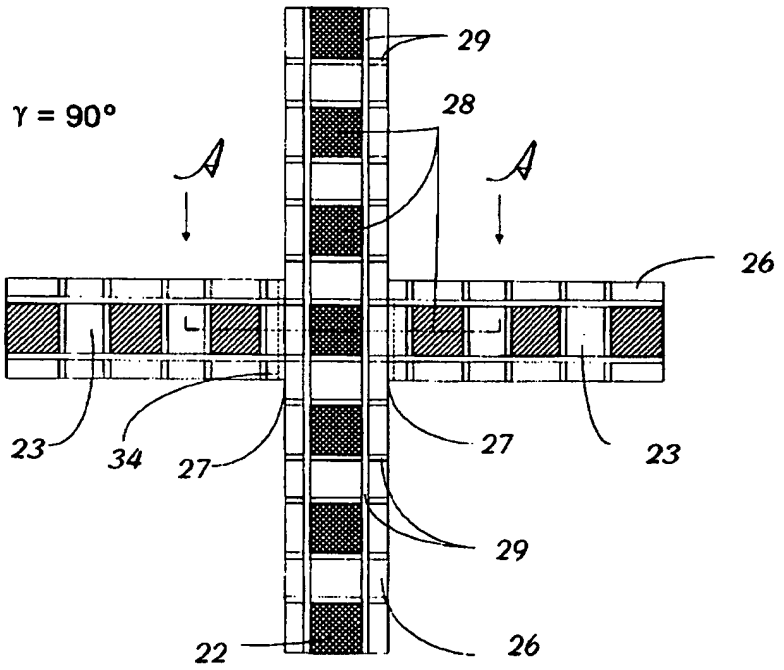
Richard E.Davidsen and Stephen W.Smith, "Sparse Geometries for Two-Dimensional Array Transducers in Volumetric Imaging" Ultrasonics Symposium, 1993, p. 1091.

Primary Examiner—Francis Jaworski

[57] **ABSTRACT**

This invention employs an ultrasound apparatus with a phased transducer having transmit and receive array systems to form an electronically scanned ultrasonic "pencil" beam (25) from crossed flat acoustic beams. The flat transmit beams and flat receive apertures are shaped by the arrays with size of individual elements on the order of the wavelength of a generated carrier frequency in a human body. The separation of array functions in the transmission and reception modes reducess the side lobe level and improves the noise performance. A fast method of acquisition of two dimensional images is described. This method uses a property of a dynamic focused and scanned flat acoustic beam together with the ability to shape flat synthetic receive apertures from digitized and memorized amplitude information. The same fast method of three dimensional image reconstruction is suggested, which uses an unfocused acoustic beam generated by a single transducer element together with the ability to form flat synthetic receive apertures in memory.

24 Claims, 15 Drawing Sheets



DOCUMENT-IDENTIFIER: US 5782762 A
TITLE: Method and system for producing interactive, three-dimensional renderings of selected body organs having hollow lumens to enable simulated movement through the lumen

---------- KWIC ---------

BSPR:
In a specific application for generating a three-dimensional rendering of a patient's colon, the patient initially undergoes a selected preparation procedure. For example, the patient's colon is initially cleansed and then inflated with air to permit the acquisition of unobstructed two-dimensional images of the colon. Next, the patient undergoes a CT scan to produce a series of two-dimensional images of the patient's internal organs. Preferably, a spiral or helical CT scanner is employed to provide a series of uninterrupted two-dimensional images through the body. The series of two-dimensional images are transferred from the scanner to a graphics computer to effect various image processing procedures. The dataset corresponding to the series of two-dimensional images may be transferred to the graphics computer in a compressed format for decompression on the graphics computer. Alternatively, the dataset representing the series of two-dimensional images may be decompressed on the computer console of the scanner prior to transfer to the

US005782762A

United States Patent [19]

Vining

[11] Patent Number: 5,782,762

[45] Date of Patent: Jul. 21, 1998

[54] **METHOD AND SYSTEM FOR PRODUCING INTERACTIVE, THREE-DIMENSIONAL RENDERINGS OF SELECTED BODY ORGANS HAVING HOLLOW LUMENS TO ENABLE SIMULATED MOVEMENT THROUGH THE LUMEN**

[75] Inventor: **David J. Vining**, Winston-Salem, N.C.

[73] Assignee: **Wake Forest University**, Winston-Salem, N.C.

[21] Appl. No.: **331,352**

[22] Filed: **Oct. 27, 1994**

[51] **Int. Cl.**[6] **A61B 5/05**

[52] **U.S. Cl.** **600/407**; 395/119; 395/924; 128/920

[58] **Field of Search** 128/653.1, 653.2, 128/653.4, 654, 920; 364/413.14, 413.19, 413.22; 378/4, 901; 395/119, 120, 924; 600/407, 410, 420, 431

[56] **References Cited**

U.S. PATENT DOCUMENTS

4,367,216	1/1983	Mutzel et al.	424/5
4,630,203	12/1986	Szirtes	364/414
4,710,876	12/1987	Cline et al.	364/414
4,719,585	1/1988	Cline et al.	364/518
4,729,098	3/1988	Cline et al.	364/414
4,737,921	4/1988	Goldwasser et al.	364/518
4,751,643	6/1988	Lorensen et al.	364/414
4,791,567	12/1988	Cline et al.	364/413.13
4,821,213	4/1989	Cline et al.	364/522
4,823,129	4/1989	Nelson .	
4,831,528	5/1989	Crawford et al.	364/413.22
4,879,668	11/1989	Cline et al.	364/522
4,958,932	9/1990	Kegelman et al.	356/372
4,984,157	1/1991	Cline et al.	364/413.13
4,985,834	1/1991	Cline et al.	364/413.22
5,047,772	9/1991	Ribner .	
5,056,020	10/1991	Feldman et al.	364/413.19
5,127,037	6/1992	Bynum	378/4
5,166,876	11/1992	Cline et al.	364/413.13
5,170,347	12/1992	Tuy et al.	364/413.22
5,187,658	2/1993	Cline et al.	364/413.13
5,204,625	4/1993	Cline et al.	324/306
5,229,935	7/1993	Yamagishi et al.	364/413.22

(List continued on next page.)

FOREIGN PATENT DOCUMENTS

0231950	8/1987	European Pat. Off. .
0514587	11/1992	European Pat. Off. .
2265775	10/1993	United Kingdom .
95/20270	7/1987	WIPO .

OTHER PUBLICATIONS

Strong et al., "Applications of three-dimensional display techniques in medical imaging", J. Biomed. Eng. 1990, vol. 12, May, pp. 233–238.

Watt, "*3d Computer Graphics*." Second Edition, Addison-Wesley Publishing Co., 1993, pp. 320–323.

T.L. Schulley, et al. "A High Resolution Nonlinearity Correcting A/D Converter Architecture," 3–6 Jun. 1993, pp. 1212–1215, 1993 IEEE International Symposium on Circuits and Systems.

Vining, D.J., Padhani, A.R., Wood, S., Zerhouni, E. A., Fishman, E. K., and Kuhlman, J. E., "Virtual Bronchoscopy: A New Perspective for Viewing the Tracheobronchial Tree." Radiology, Nov. 1993 vol. 189 (P).

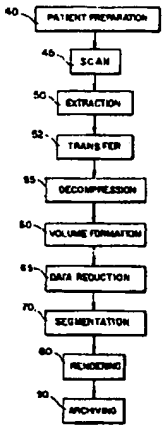
Primary Examiner—Brian L. Casler

Attorney, Agent, or Firm—Dann, Dorfman, Herrell and Skillman, P.C.

[57] **ABSTRACT**

A method and system are provided for effecting interactive, three-dimensional renderings of selected body organs for purposes of medical observation and diagnosis. A series of CT images of the selected body organs are acquired. The series of CT images is stacked to form a three-dimensional volume file. To facilitate interactive three-dimensional rendering, the three-dimensional volume file may be subjected to an optional dataset reduction procedure to reduce pixel resolution and/or to divide the three-dimensional volume file into selected subvolumes. From a selected volume or subvolume, the image of a selected body organ is segmented or isolated. A wireframe model of the segmented organ image is then generated to enable interactive, three-dimensional rendering of the selected organ.

156 Claims, 25 Drawing Sheets



DOCUMENT-IDENTIFIER: US 6083162 A
TITLE: Method and system for producing interactive, three-dimensional renderings of selected body organs having hollow lumens to enable simulated movement through the lumen

---------- KWIC ---------

BSPR:
In a specific application for generating a three-dimensional rendering of a patient's colon, the patient initially undergoes a selected preparation procedure. For example, the patient's colon is initially cleansed and then inflated with air to permit the acquisition of unobstructed two-dimensional images of the colon. Next, the patient undergoes a CT scan to produce a series of two-dimensional images of the patient's internal organs. Preferably, a spiral or helical CT scanner is employed to provide a series of uninterrupted two-dimensional images through the body. The series of two-dimensional images are transferred from the scanner to a graphics computer to effect various image processing procedures. The dataset corresponding to the series of two-dimensional images may be transferred to the graphics computer in a compressed format for decompression on the graphics computer. Alternatively, the dataset representing the series of two-dimensional images may be decompressed on the computer console of the scanner prior to transfer to the

US006083162A

United States Patent [19]

Vining

[11] Patent Number: 6,083,162

[45] Date of Patent: *Jul. 4, 2000

[54] **METHOD AND SYSTEM FOR PRODUCING INTERACTIVE, THREE-DIMENSIONAL RENDERINGS OF SELECTED BODY ORGANS HAVING HOLLOW LUMENS TO ENABLE SIMULATED MOVEMENT THROUGH THE LUMEN**

[75] Inventor: **David J. Vining**, Winston-Salem, N.C.

[73] Assignee: **Wake Forest University**, Winston-Salem, N.C.

[*] Notice: This patent is subject to a terminal disclaimer.

[21] Appl. No.: **08/817,901**

[22] PCT Filed: **Oct. 27, 1995**

[86] PCT No.: **PCT/US95/14022**

§ 371 Date: **Apr. 28, 1997**

§ 102(e) Date: **Apr. 28, 1997**

[87] PCT Pub. No.: **WO96/13207**

PCT Pub. Date: **May 9, 1996**

Related U.S. Application Data

[63] Continuation-in-part of application No. 08/331,352, Oct. 27, 1994.

[51] **Int. Cl.**[7] **A61B 5/05**

[52] **U.S. Cl.** **600/407**; 345/420; 345/424; 345/429; 345/433; 128/920

[58] **Field of Search** 600/407, 410, 600/420, 431; 378/4.901; 345/419–443, 952; 395/924; 128/920

[56] **References Cited**

U.S. PATENT DOCUMENTS

4,367,216	1/1983	Mutzel et al.	424/5
4,630,203	12/1986	Szirtes	364/414
4,710,876	12/1987	Cline et al. .	
4,719,585	1/1988	Cline et al. .	
4,729,098	3/1988	Cline et al. .	
4,751,643	6/1988	Lorensen et al. .	

(List continued on next page.)

OTHER PUBLICATIONS

Vining, D.J., Padhani, A.R., Wood, S., Zerhouni, E.A., Fishman, E.K., and Kuhlman, J.E., "Virtual Bronchoscopy: A New Perspective for Viewing the Tracheobronchial Tree." Radiology. Nov. 1993, vol. 189 (P).

Watt, Alan. "3D Computer Graphics." 2nd Edition, Addison–Wesley Pub. Co., 1993, p. 320–323.

Strong et al., "Applications of Three–Dimensional Display Techniques in Medical Imaging," J.Biomed. Eng. 1990, vol. 12. May, pp. 233–238.

Oikarinen et al., "Rendering System for Tomographic Images.".

"Rendering System for Tomographic Images," IEEE, p. 144–145, Copyright 1993.

WO 91/14397 Hardy, Tyrone L.; Three dimensional Graphics Simulation and actual imaging data composite Display; Oct. 3, 1991; pp. 1–18.

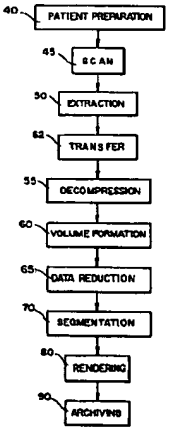
WO 94/24640 Karron, Daniel and Mishra, Bhubaneswar; system & method for surface rendering of internal structures within the interior of a solid object; Oct. 27, 1994 pp. 1–40.

Primary Examiner—Brian L. Casler
Attorney, Agent, or Firm—Dann, Dorfman, Herrell & Skillman, P.C.

[57] **ABSTRACT**

A method and system are provided for effecting interactive, three-dimensional renderings of selected body organs for purposes of medical observation and diagnosis. A series of CT images of the selected body organs are acquired. The series of CT images is stacked to form a three-dimensional volume file. To facilitate interactive three-dimensional rendering, the three-dimensional volume file may be subjected to an optional dataset reduction procedure to reduce pixel resolution and/or to divide the three-dimensional volume file into selected subvolumes. From a selected volume or subvolume, the image of a selected body organ is segmented of isolated. A wireframe model of the segmented organ image is then generated to enable interactive, three-dimensional rendering of the selected organ.

129 Claims, 25 Drawing Sheets



DOCUMENT-IDENTIFIER: US 6236875 B1
TITLE: Surgical navigation systems including reference and localization frames

---------- KWIC ---------

DEPR:
Pre-operative imaging occurs as usual and the skeletal elements may be discriminated from the soft tissue in the image data set as above. In particular, a CT scan of the skeletal elements 10, 20, 30 could be taken prior to the procedure. Processor 104 may then discriminate the skeletal elements and store the pre-procedural image data set in memory 106. Next, the patient is immobilized for the procedure. A radiograph of the skeletal anatomy of interest is taken by a radiographic device equipped with emitters detectible by the digitizer. For example, a fluoroscopic localizer 136 is illustrated in FIG. 7. Localizer 136 includes a device which emits x-rays such as tube 138 and a screen 140 which is sensitive to x-rays, producing an image when x-rays pass through it. This screen is referred to as a fluoroscopic plate. Emitters 142 may be positioned on the tube 138, or on the fluoroscopic plate 140 or on both. For devices in which the tube 138 is rigidly attached to the plate 140, emitters need only be provided on either the tube or the plate. Alternatively, the reference array 110 may be attached to the tube or the plate, obviating the need for emitters on this element. By passing

US006236875B1

(12) **United States Patent**
Bucholz et al.

(10) **Patent No.: US 6,236,875 B1**
(45) **Date of Patent: *May 22, 2001**

(54) **SURGICAL NAVIGATION SYSTEMS INCLUDING REFERENCE AND LOCALIZATION FRAMES**

(75) Inventors: **Richard D. Bucholz**, St. Louis, MO (US); **Kevin T. Foley**, Memphis, TN (US); **Kurt R. Smith**, Boulder, CO (US); **Daniel Bass**, Moss Beach, CA (US); **Thomas Wiedenmaier**, San Carlos, CA (US); **Todd Pope**, San Francisco, CA (US); **Udo Wiedenmaier**, San Mateo, CA (US)

(73) Assignees: **Surgical Navigation Technologies**, Broomfield, CO (US); **St. Louis University**, St Louis, MO (US)

(*) Notice: This patent issued on a continued prosecution application filed under 37 CFR 1.53(d), and is subject to the twenty year patent term provisions of 35 U.S.C. 154(a)(2).

Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **08/809,404**

(22) PCT Filed: **Oct. 5, 1995**

(86) PCT No.: **PCT/US95/12894**

§ 371 Date: **Jul. 23, 1997**

§ 102(e) Date: **Jul. 23, 1997**

(87) PCT Pub. No.: **WO96/11624**

PCT Pub. Date: **Apr. 25, 1996**

Related U.S. Application Data

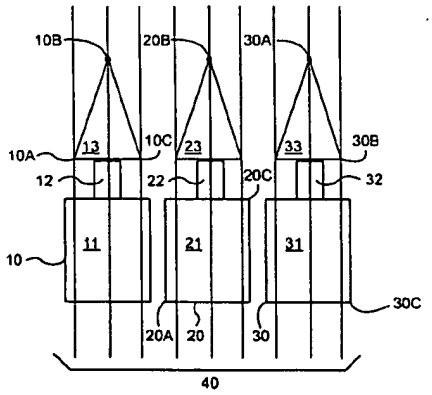
(63) Continuation-in-part of application No. 08/319,615, filed on Oct. 7, 1994, now abandoned.
(60) Provisional application No. 60/003,415, filed on Sep. 8, 1995.

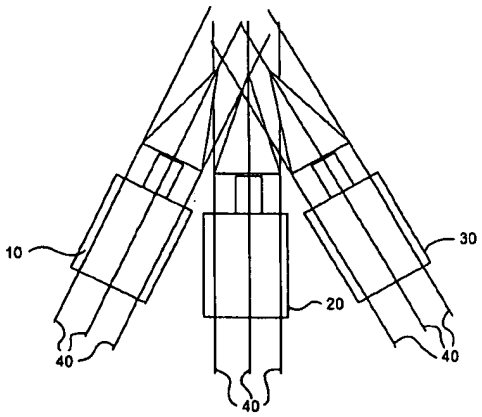
(51) **Int. Cl.**[7] **A61B 5/05**
(52) **U.S. Cl.** **600/407**; 606/130
(58) **Field of Search** 600/407, 410, 600/414, 415, 417, 425, 426, 429, 437; 606/130

(56) **References Cited**

U.S. PATENT DOCUMENTS

D. 291,246	8/1987	Lower .	
D. 349,573	8/1994	Bookwalter .	
D. 353,668	12/1994	Banks .	
D. 357,534	4/1995	Hayes .	
D. 359,557	6/1995	Hayes .	
3,821,469	6/1974	Whetstone et al. .	
3,868,565	2/1975	Kuipers .	
3,963,028	6/1976	Cooley et al. .	
3,983,474	9/1976	Kuipers	324/43 B
4,058,114	11/1977	Soldner .	
4,068,156	1/1978	Johnson et al. .	
4,117,337	9/1978	Staats .	
4,182,312	1/1980	Mushabac	433/68
4,209,254	6/1980	Reymond .	
4,259,725	3/1981	Andrews et al. .	
4,341,200	7/1982	Perry .	
4,341,220	7/1982	Perry	606/130
4,358,856	11/1982	Stivender et al. .	
4,368,556	1/1983	Wanner et al. .	
4,396,945	8/1983	DiMatteo et al. .	
4,398,540	8/1983	Takemura et al. .	
4,407,298	10/1983	Lentz et al. .	
4,419,012	12/1983	Stephenson .	
4,457,311	7/1984	Sorenson et al. .	
4,465,069	8/1984	Barbier et al. .	
4,473,074	9/1984	Vassiliadis .	
4,506,676	3/1985	Duska .	
4,543,959	10/1985	Sepponen .	
4,571,834	2/1986	Fraiser et al. .	
4,583,538	4/1986	Onic et al. .	
4,585,350	4/1986	Pryer et al. .	
4,592,352	6/1986	Patil .	
4,602,622	7/1986	Bar et al. .	
4,608,977	9/1986	Brown	128/303 B
4,638,798	1/1987	Sheldon et al.	128/303 B
4,649,504	3/1987	Krouglicof et al. .	
4,651,732	3/1987	Frederick .	
4,659,971	4/1987	Suzuki et al. .	
4,660,970	4/1987	Ferrano	356/1





x-rays through the skeletal element 141 of interest, a two-dimensional image based on bone density is produced and recorded by the plate. The image produced by the fluoroscopic localizer 136 is determined by the angle of the tube 138 with respect to the plate 140 and the position of the skeletal elements therebetween and can be defined with respect to procedure coordinates (surgical space). Fluoroscopic localizer 136 includes a processor which digitizes the image on the plate 140 and provides the digitized image to processor 104 for possible processing and subsequent storage in intra-procedural geometry data memory 121. Processor 104 may simulate the generation of this two-dimensional x-ray image by creating a series of two-dimensional projection of the three-dimensional skeletal elements that have been discriminated in the image data set stored in memory 106. Each two dimensional projection would represent the passage of an X-ray beam through the body at a specific angle and distance. In order to form the displaced data set and thus achieve registration, an iterative process is used which selects that a two-dimensional projection through the displaced data-set that most closely matches the actual radiographic image(s) stored in memory 121. The described process can utilize more than one radiographic image. Since the processor 104 is also aware of the position of the fluoroscopic localizers because of the emitters 142 thereon, which are in communication with localizer 108, the exact position of the skeletal elements during the procedure is